Available online at www.sciencedirect.com
ScienceDirect
Renewable and Sustainable Energy Reviews
12 (2008) 2422–2437

RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS

www.elsevier.com/locate/rser

Valuation for renewable energy: A comparative review

Angeliki Menegaki*

Department of Economics, University of Crete, University Campus, 74100 Rethymno, Greece

Received 15 March 2007; accepted 21 June 2007

Abstract

Environmental cost–benefit analysis is applied for the evaluation of renewable energy projects. Since some benefits and costs do not have monetary values, economic valuation techniques are applied to estimate them. This paper reviews the literature on the valuation/evaluation of renewable energy resources and summarizes the methods used in them. It discerns four main streams of valuation in renewable energy. The first is economic, welfare oriented and comprises stated and revealed preference methods; the second is the financial option analysis with a financial background; the third is emergy analysis, which is mostly an ecological engineering-based method with capable economic links, and the fourth is again economic but not welfare based. The paper discusses the main directions discerned in these studies and recognizes first that proper valuation takes place only in the first method while the other methods describe only evaluation procedures and second that there is a research gap that has yet to be filled in as compared to other areas of environmental, resource and energy economics.

Keywords: Cost–benefit analysis; Emergy analysis; Real option; Revealed preference; Stated preference

Contents

*Corresponding address Z. Pigis 22, 71307 Heraklion, Crete, Greece. Tel.: +30 6972443546.
E-mail address: amenegaki@her.forthnet.gr

1364-0321/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2007.06.003

1. Introduction

Renewable energy creates multiple public benefits such as environmental improvement (reduction of power plant greenhouse emissions, thermal and noise pollution), increased fuel diversity, reduction of energy price volatility effects on the economy, national economic security (fossil energy is vulnerable to political instabilities, trade disputes, embargoes and other disruptions [1]), increase of economic productivity and GDP through more efficient production processes. It has been estimated that a 10% increase in renewable energy share avoids GDP losses in the range of \$29–\$53 billion in the US and the EU (\$49–\$90 billion for OECD). These avoided losses offset half the renewable energy OECD investment needs projected by a G-8 Task Force. For the US, each additional Kw of renewable energy avoids on average \$250–\$450 in GDP losses. The offset is worth approximately \$200/Kw for wind and solar and \$800/Kw for geothermal and biomass. The societal valuation of non-fossil alternatives must reflect these avoided GDP losses, whose benefit is not fully captured by private investors [2]. Furthermore, renewable energy offers development benefits (prevention of money flow abroad, electrification of rural and remote villages in developing countries and new jobs). Some renewable technologies like biomass are labor intensive because growing, harvesting and transporting biomass fuels require labor [3]. According to the New York State Energy Office, wind energy systems create 25–70% more jobs than conventional power plants producing the same amount of electricity [4].

The need for renewable energy investment is apparent because of the earth's finite resources depletion. Fossil fuels draw on finite resources, which eventually dwindle, become too expensive or too environmentally damaging to retrieve [1]. Renewable energy is nevertheless subject to some disadvantages, e.g., wind energy has to face concerns over the visibility and noise of wind turbines, land use, bird deaths from electrocution or collision with the spinning rotors. Also, solar power systems may generate no air pollution, but the environmental issues here relate to how they are manufactured, installed and disposed of. Energy from biomass derived from the burning of plant matter (e.g., wood) raises air pollution concerns. On the other hand, biomass reduces air pollution by being part of the carbon cycle, reducing carbon dioxide emissions by 90% compared with fossil fuels [3].

Last, although on a small scale renewable energy is not competitive when compared to bulk power generation, it is when the external costs of producing energy from fossil fuels are also taken into account [5]. Renewable energy has practical applications in innovative niche markets, such as consumer products, remote/off-grid and telecommunications. The cost of renewable energy technologies will drop once the benefits of renewable energy, including its sustainable nature and the minimal pollution it creates, are recognized by a larger percentage of the population.

A typical environmental cost–benefit analysis contains the following eight steps [6]: (1) definition of project (gainers or losers identification), (2) identification of project impacts (e.g., landscape effects, odor, bird electrocution, job creation), (3) find out which impacts are economically relevant (namely those that increase the quality and quantity of goods that generate positive utility or cause reduction in the price at which they are supplied), (4) physical quantification of relevant impacts (physical amount of benefit and cost flows and time occurrence identification), (5) monetary valuation of relevant effects, (6) discounting of cost and benefit flows, (7) applying the net present value test and (8) sensitivity analysis. Valuation takes place at the fifth step, while the evaluation is the whole procedure described above as cost–benefit analysis. This paper suggests first that an all-inclusive evaluation is achieved only through the involvement of valuation approaches for non-monetary inputs by specifically seeking the total economic value of renewable energy (use value plus non-use value) as explained in Fig. 1, which has been drawn by Bateman and Langford [7] and then adjusted for renewable energy values in the current paper.

The use value is derived from the actual usage of renewable energy. For renewable energy users, the use value is composed of (i) the direct use value (e.g., people use renewable energy to have their homes electrified), (ii) the indirect use value (e.g., using renewable energy whenever possible saves non-renewable energy for other purposes and thus reduces pressure on oil demand), (iii) option use value (people save non-renewable energy for the future). The non-use value is utility from not using the good. This consists of (i) the bequest-value (the value people enjoy from bequeathing a clearer environment to the next generation as a result of reduced emissions) and (ii) the existence value (value from enjoying a clearer atmosphere today from reduced air emissions). All the above constitutes the human value of renewable energy. The intrinsic value of renewable energy (which is also a non-human value) is the value from keeping fossil fuels intact. Despite the ongoing discussion on the ethics of including the passive use values in economic analysis [8,9] and

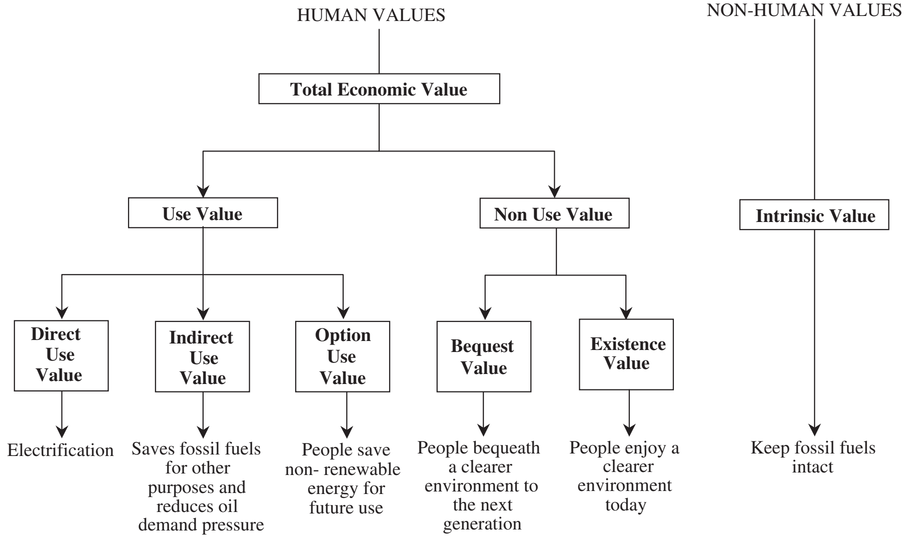


Fig. 1. Total value disaggregation for renewable energy.

the technical criteria the methods should comply with, a benefit–cost analysis that omits this value is incomplete or misleading [10].

Contrary to revealed and stated preference methods, financial option theory performs evaluation taking into account the flexibility of renewable energy projects. However, the flexibility aspect could be described as an attribute of renewable energy and valuated, as is done with the rest of the attributes of renewable energy, under the stated preference framework. As regards emergy analysis, this also follows the steps of cost–benefit analysis after omitting steps 5–7. Last, all methods referred to in Section 2.5 of this paper follow the logic of benefit–cost analysis.

After this introduction, the rest of the paper is organized as follows. The second part consists of five sub-parts, one for each method. The third part is the conclusion where the main findings of the paper are summed up. Noteworthy in the sections that follow for each method, is the interchanging appearance of the words valuation and evaluation. Although the paper states the reason why these two words have a different meaning, literature in the various areas presented next, uses the terms interchangeably.

2. Valuation methods

Studies on renewable energy valuation have been grouped in five main methods, usually depending on the research field from where the research is launched. These methods are stated preference techniques, revealed preference techniques, portfolio analysis, emergy analysis and various other economic but not welfare-based oriented methods. The paper briefly presents the logic of each method and provides examples of relevant studies. Table 1 summarizes all the studies referred to in this paper.

2.1. Stated preference techniques

This type of studies specifically seeks the willingness-to-pay (WTP) of an individual in order to secure a benefit from renewable energy or WTA to forego a benefit. Contingent valuation and choice modeling are examples of stated preference techniques. Contingent valuation has been employed for the estimation of WTP for renewable energy and the factors that affect it [11,15,19–21], for the evaluation and choice among various alternative renewable energy choices e.g., wind, hydro and biomass [13,18], for the examination of the form of payment e.g., whether collective or private [14,44] etc. This paper will not comment on the actual WTP produced by each study. After all, WTP results themselves should not be interpreted as actual WTP but rather as an index of consumers' relative preferences [19]. In summary, WTP is higher among respondents with high incomes [14,45] although in one piece of research the opposite is found too [15]. The latter is inconsistent with economic theory, but the author attributes this to the fact that respondents with lower incomes put more weight to jobs created by the wind power installations. Also WTP is higher among younger people [14,15,21], those who are more liberal, do not rent their home, are women, do not have children and are highly educated [14]. The latter is also confirmed in [15]. Also, attitudinal factors affect WTP, namely those who believe that their family and friends would also support renewable energy are also more willing to pay themselves [14]. WTP increased when an individual had an interest in environmental issues [15,19]. WTP is also sensitive to the number of cancer cases caused by the usage of non-renewable energy and appliance use restrictions [19]. Furthermore as regards the choice

Table 1
Studies on the valuation of renewable energy resources

Country	Resource type	Method	Result	Study
Japan	Photovoltaic and wind energy	CVM	2000¥ = 17US$ in the form of a flat monthly surcharge, exchange rate 115¥/US$	[11]
Spain	Wind energy	Conjoint analysis	Environmental costs appear higher in choice modeling that in contingent rating. Estimates of environmental costs are 3580, 6290 and 6161 pesetas for cliffs, fauna and flaura and landscape	[12]
Scotland (North Assynt Estate)	Three-turbine wind farm, small-scale hydro scheme and biomass development	Local economic impact and CVM	Mean overall visitor expenditure per day = £21.50 Mean WTP for wind farm = £13,585, hydro scheme = £6642, biomass development = £14.282	[13]
Scotland	Renewable energy investments (hydro, wind and biomass)	Choice experiments	The implicit price to maintain a neutral impact on wildlife is 75% of the price households would pay to reduce landscape impacts form high to none Rural respondents would be willing to pay an additional £1.08 per year from each household	[45]
USA	Renewable energy	CVM (single-bounded dichotomous choice question)	Scenario with collective payment and private provision most preferable	[14]
Sweden	Wind energy	CVM	WTP increased with age, income and environmental awareness	[15]
USA	Green electricity	Choice experiment	Positive WTP for green electricity. Solar energy most preferred. Biomass and farm methane least preferred	[16]
USA	Green electricity	Conjoint analysis and Hedonic analysis	Higher WTP when emissions reductions stem from increased reliance upon renewable resources	[17]
UK	Green electricity	CVM	WTP varies with social status and income	[18]
Wisconsin, USA	Green electricity	CVM (ordered probit model)	WTP higher when cancer cases decreased, appliance use restrictions were imposed and fish consumption bans as well sugar maple damage rates decreased	[19]
Schools in Hong-Kong	Photovoltaic electricity	CVM	Positive WTP	[20]

Texas	Renewable energy	CVM (Town meetings of 200–250 citizens)	Higher WTP with age, education, income and information	[21]
USA	Photovoltaics in electricity production	Portfolio analysis	Photovoltaic-based electricity has a negative beta; its insurance value offsets its lower returns	[2]
USA	Combined budget on research, development and deployment of renewables	Real options valuation, binomial lattice method	Total real options value 104 billion US$ (year base 2002)	[22]
USA	Wind power	CAPM, futures and swaps	0.50 ¢/kWh premium over expected spot prices to lock in natural gas prices for the next 10 years	[23]
USA	Renewable electric technologies	Real options	The value of renewable electric technologies is $30.6 billion	[24]
Spain	Switchable tariffs in wind energy	Real options	Monthly switching tariff is of more value to wind generators for its great flexibilities and accuracy of short-term forecasts	[25]
Greece	Electricity from renewable energy resources	Expanded net present value/real options valuation	NPV $= -405 <$ option value $= 755$	[26]
USA (Mississippi river)	Natural energies (e.g., river geopotential) in river deltas	Emergy analysis	Emergy ratios 33.2 and 9.36	[27]
Oak Openings region in USA	Environmental, cultural and economic subsystems	Emergy analysis	Emergy ratio 1.57	[28]
Louisiana, USA	Wetland valuation (commercial fishing and trapping, recreation and storm protection)	CVM and emergy analysis based methods	Present value of an average acre of natural wetlands is US$2429–6400 per acre (8% discount rate) to $8977–17,000 per acre (3% discount rate). The lowest value of the wetlands is $77 m and the largest value is $544 m.	[29]
Scotland	Hydroelectricity	Long-run average value	0.00–0.05 p/m^3 compared to gas or coal with no CO_2 emission charges included. 0.07–0.18 p/m^3 compared to gas or coal with CO_2 emission charges included	[30]
USA, Australia	Renewable resources	Replacement cost in the construction of indexes ISEW, GPI, SNBI/indirect valuation of renewables through the valuation of depletion of non-renewables	Equals the replacement cost of non-renewables	[31]
Netherlands, Sweden, UK, USA	Renewable resources	Replacement cost of non-renewables in the construction of ISEW and GPI indexes/ indirect valuation of renewables through the valuation of depletion of non-renewables	Equals the replacement cost of non-renewables	[32]

Table 1 (*continued*)

Country	Resource type	Method	Result	Study
121 cities in USA	Renewable water production	Link between ecosystem service valuation with ecological footprint analyses	Mean cost associated with footprints $ 88,808 $km^{-2} yr^{-1}$	[33]
–	Electricity externalities (meta-analysis)	Comparison of abatement cost and damage–cost approaches with ANOTA analysis	Bottom-up approaches produce the lowest external cost estimates	[34]
Canada	Metals	Cost of replacement, imposition of royalty rates on mined product revenue	–	[35]
Ethiopia, Nepal, Ghana and India	Crop production increase, forestry, land management, cropping promotion	Short-cut techniques such as marginal user cost to add at the shadow price, multi-criteria analysis, and non-market valuation	–	[36]
Rodriguez, Mauritius	Renewable energy	Discounted flow analysis, multi-criteria analysis	–	[37]
Qatar	Wind energy	Interest recovery factor, lifetime of the wind energy conversion system, investment rate and operation and maintenance costs	–	[38]
Egypt	Wind energy, photovoltaics	Life cycle cost analysis (present value)	Wind energy has the lowest cost	[39]
Bangladesh	Photovoltaics and grid electricity	Life cycle cost analysis	Life cycle cost per unit of grid energy is much higher than that of photovoltaic energy	[40]
Greece	Renewable energy	Multicriteria analysis	–	[41]
Greece	Biogass	Total annual cost	Biogas generated energy cheaper than conventional	[42]
Greece	Biogass	Total annual cost	More electricity generator units will avoid the loss of renewable energy produced by biogas	[43]

between private and public provision and voluntary or collective payment, WTP is higher under collective payment (for free-riding prevention) than under private provision, suggesting lower faith in government provision [14]. Opposite evidence is provided by Ivanova [44] who found that WTP is higher in the voluntary payments framework rather than in the mandatory one. Continuing with the factors that affect WTP, it has been stated that, without any significant changes in current consumer choice or legislation, any marketing efforts will not attain success [18]. Results indicate that at currently offered green tariff levels, demand for such products is not significant enough to result in the building of new renewable capacity. Last, as regards the preferences for different types of renewable energy, hydro is more preferred as compared to wind and biomass [13]. Biomass appears to be the least preferred form of renewable energy in a study by Borchers et al. [16] where choice experiments are conducted to explore preferences for renewable energy.

Fewer studies on renewable energy benefits employ choice experiments [12,16] or conjoint analysis [45] as compared to the aforementioned number of contingent valuation studies. Bergman et al. [45] studied the attributes of renewable energy investments in Scotland and they used choice experiments. They found the implicit price to maintain a neutral impact on wildlife and that WTP is sensitive to additional full time jobs created by the renewable projects. Choice experiments have also been used [16] to explore preferences for green electricity programmes. A positive WTP is derived for green energy electricity. Differences between voluntary and non-voluntary programmes are also found while many consumers have negative WTP for non-voluntary programmes in cases of less preferred forms of renewable energy e.g., biomass. Conjoint analysis is used [12] to quantify public preferences over the environmental impacts of wind farms and their results show that significant social costs in the form of environmental impacts can be associated with wind farm developments.

2.2. Revealed preference techniques

The WTP information is given out by markets, as produced by consumers' actual decisions. Travel cost and hedonic pricing are revealed preference techniques. No travel cost study relative to renewable energy has been found by the writer of the paper. Hedonic analysis though has been used together with conjoint analysis in one study by Roe et al. [17]. This study peruses hedonic analysis of price premiums charged in US deregulated electricity services and finds that the percent of power supplied by renewable energy is one key determinate; a 1% increase in such sources increases the premium for a household using 1000 kWh per month by about \$6 per annum. Certification, brand name and state of offer also help explaining the premium structure. Their results suggest that US consumers value environmental benefits created from renewable energy and that firms have captured this value in their pricing schemes.

2.3. Financial option theory—portfolio analysis

Energy economics employ two financial approaches that incorporate risk in resource planning: risk adjusted discount rates and options theory. They are complementary approaches and are an improvement over the standard present value revenue requirements [46]. Portfolio analysis (CAPM) valuates projects in line with their anticipated risks (opportunities to alter and delay investment are important components of market risk [22]

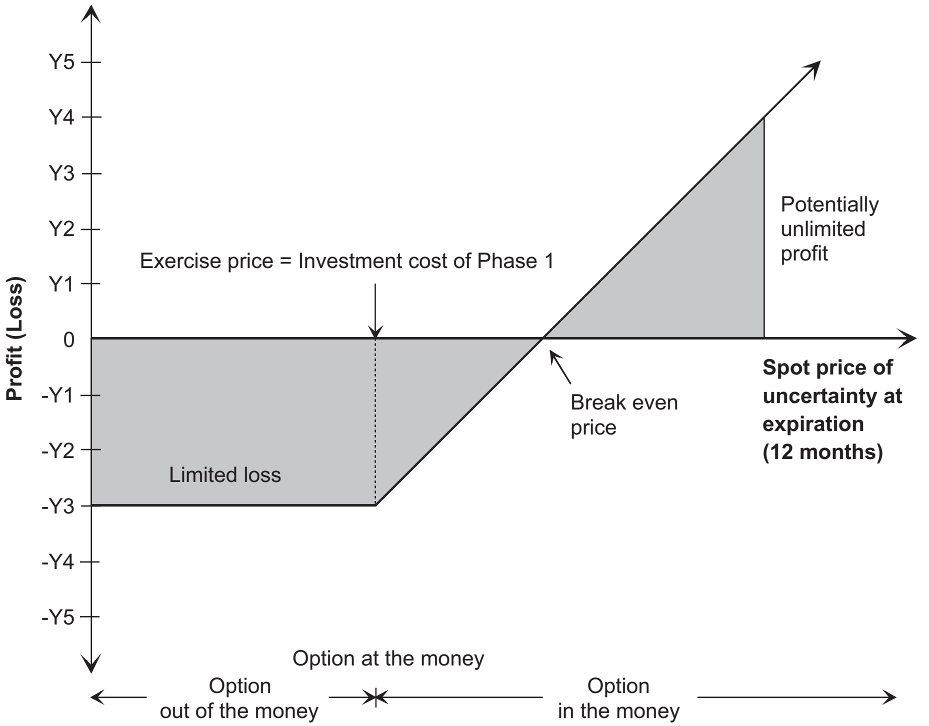
and uncertainty which stems from the cost fluctuations of non-renewables and technology) and returns. CAPM forms a relationship between risk and the required return and assumes that total risk is divided in two sources: One is the systematic risk e.g., the state of the economy that affects all assets and the other is the unsystematic risk that is specific to a project. As known, CAPM shows that the unsystematic risk is irrelevant to the highly diversified holder of securities (in our case types of energy) because the effects of such disturbances cancel out on average in the portfolio.

The use of financial theory and methods increase as the energy industry becomes more and more deregulated. Contrary to the static engineering–economics approaches, financial theory approaches valuate renewables not on the basis of their stand-alone cost, but on the basis of their overall portfolio cost coupled with expected portfolio risk (year-to-year cost fluctuations). Quality and market responsiveness—two important attributes of new manufacturing technologies cannot be modeled easily in terms of cash flows. Thus, "photovoltaics and similar renewables offer a unique cost–risk menu along with other valuable attributes that traditional valuation models, conceived long before such attributes became technologically feasible, cannot see because they are steeped in the vocabulary and measurement concepts of a different technological era" [47]. Although photovoltaics cost more, they reduce the cost of a fossil-generating portfolio at any given level of risk because their random risk (technology risk) is fully diversifiable.

Financial and real option theory is used for hedging against risk and uncertainty caused by fossil fuel price volatility, environmental regulations changes, demand supply, technology and market structure uncertainty. The link between the renewable energy project evaluation and the literature on valuing financial options lies in that, when undertaking an investment, there is value that derives from having the option to abandon, delay or modify when new information becomes available. A main feature of the real options approach is the inclusion of the possibility of delaying an investment and taking into account the value of waiting as part of the decision-making problem. The value of waiting can be explained as follows: if a company invests at time t, it gets the expected present value of the revenues minus the cost. In contrast, if it waits and invests at time $(t+1)$, a real option might arise that, if exercised, yields a higher net profit [48].

Therefore, the value of renewable energy projects incorporates the option value of flexibility in operating the asset subject to market risk. An option is a financial instrument that gives the holder the right—but not the obligation—to sell (put) or buy (call) another financial instrument at a set price and expiration date. If the holder of the option chooses to buy the asset (the underlying asset) we say that he exercises the option, paying the fixed exercise price to receive the underlying asset. This would occur only if the market price of the asset is higher than the exercise price at maturity exercise date. From a theoretical standpoint, the value of an option comprises two components: intrinsic value (immediate exercise value of the option) and time value (the excess of the option value). The analogy between a financial option and a real option is that "an investment opportunity (e.g., building a plant) is like a call option where the management has the right but not the obligation to acquire the assets of an operational project" [26]. The irreversible investment cost that is committed at the initiation of the investment project plays the role of the exercise price and the real asset is the project once this starts producing cash flows.

The applicability of option theory in renewable energy evaluation stems from the modularity characterizing renewable energy projects. The analogy of the financial option and the real option is shown schematically in Fig. 2. Suppose an electricity company is



Inflows	All possible cash flows generated by plant completion	Liquidation of initial investment	All posible cash flows generated by investing the initial investment amount in more profitable projects
Outflows	Initial investment cost plus final investment cost	- - -	Cost of money stemming from the initial investment cost

Fig. 2. Profit from a real option for various spot prices of uncertainty (source: Shapiro A.C., 1996 [49]).

building a new plant whose construction takes place in two phases and will be completed in 12 months. The company incurs an initial investment half of the final cost, which is also the exercise price of the call option. If at the time the other half of the company's payment is due i.e., in 12 months, exogenous factors suggest abandoning the project, the company would exercise the option, liquidate the assets and get the initial incurred cost back. Getting the money back is an option at-the-money. Putting the saved money in other more profitable uses, renders the option in-the-money. If exogenous factors suggest going on with the project, then construction is completed and the option expires and is out-of-the money.

Another study by Venetsanos et al. [26] also uses the Black–Scholes model to valuate a project and they show that its option value is positive, while its net present value was negative. Had the latter been used as a decision rule, then significant value adding aspects of the project would have been overseen. In a valuation of the benefits from research, development and deployment from renewable energy, traditional net present value is negative [22], meaning that these projects should be abandoned. However, the traditional

method fails to capture the important options or insurance value. It does not consider uncertainty in the cost of non-renewable energy; it does not consider the ability of adjusting research effort, or the technical risk associated with research, development and deployment. The real options value in the above study is regarded as being akin to that of a compound American call option (N.B. An American option can be exercised at any time up to the expiration date juxtaposed to its European counterpart, which can be exercised only at maturity. A compound option is an option on an option. A listed call option is an option of a firm's equity, which in turn is an option on the firm's assets [50]). Conclusively, the real options value derives from the right of demanding asset liquidation of a renewable energy project at any time regarded as most profitable.

Real option pricing techniques are used to valuate renewable electric technologies in the face of uncertain fossil fuel prices [24] and the switchable tariff for wind generators in Spanish electricity markets [25]. The latter shows that monthly switching tariff is of more value to wind generators for its great flexibilities and accuracy of short-term forecasts.

Furthermore, many energy-trading companies began offering financial options on energy commodities. A major complication in evaluating options in electricity markets is that electricity, unlike other commodities, cannot be stored. The price stability benefit that wind and other renewables provide has been quantified [23] by equating it with the cost of achieving price stability through other means, particularly gas-based financial derivatives (futures and swaps). This study has found that over the years 2000–2001 natural gas consumers have had to pay a premium of roughly 0.50 cents/kW over expected spot prices to lock in natural gas prices for the next 10 years. This result favors investments in wind power and other renewable technologies.

2.4. Emergy analysis

Emergy is an alternative to market evaluation for determining the net value of environmental projects to human society and is the common denominator used to express the value of environmental and economic work. This method is not usually met in economics but rather in ecological engineering. Emergy is an expression in one type of energy (solar energy) of all the available energy used in the work process, directly and indirectly that generates a product or service. It accounts for what energy is ''invested' e.g., time, materials, effort, etc., to determine worth. Economic analyses and the economic market only recognize monetary values, but economies rely on very large inputs from the environment. However, due to lack of accounting for inputs and outputs that are not directly valued on a monetary basis, such as river sediments and marsh productivity in the case of river diversions, such approaches often underestimate environmental contributions [27]. Emergy analysis assesses all the inputs that supply a system, especially those that are usually neglected by classic economic accounting methods, by means of a thermo-dynamics-based measure, giving an appraisal of the actual environmental cost of any class of resource which is not merely limited to its economic price or energetic content [51]. Emergy analysis has been used to evaluate natural and human contributions required to construct and operate two diversions within the Mississippi River Delta [27]. Other examples of the application of the method are in the valuation of environmental, cultural and economic subsystems in Oak Openings region [28], of a region with reference to its population, human activities, natural cycles, infrastructures and other settings to define geographies based on the environmental accounting of resource fluxes

and their location within a territory [51]. Different ecological and economic zones within an urban system have been shown in an attempt to understand how energy converges in the spatial context, and how multiple components interact and self-organize in a symbiotic manner during evolutionary processes. Last, emergy analysis can be used in a combination with the contingent valuation. This has been done in a valuation of wetland ecosystems [29].

2.5. Other economic approaches

This section includes various other economic methods and techniques that do not fall under the above groups and are not welfare-based either. These rely on direct costs and ignore managerial and strategic options (capability options for managers by creating opportunities to serve new customers or provide different levels of quality and reliability as well as different types of services) that may appear and they assume a more deterministic style. For example, traditional approaches ignore cost-of-quality in electricity production and delivery [52]. These are: long-run average value (based on cost considerations), ecological footprints, replacement cost, abatement and damage cost approaches, multi-criteria analysis, life-cycle cost analysis, total annual economic cost, etc. Although these techniques may not produce theoretically correct welfare measures, they provide nevertheless reasonable approximations in a transparent and timely manner [36]. Next follows a résumé of representative examples of studies falling under this category.

The derivation of the long-run average value of water in hydroelectric generation in Scotland [30] is a study that actually values water based on a comparison of generation costs between hydropower and the cost of the next reasonable alternative generating capacity. The difference in cost can be considered as the social value of water. According to study results, despite the non-consumptive nature of water in hydro and the lack of detailed spatial and temporal information that would depict the environmental impact caused by water drawing, the lowest social value is found in hydroelectric generation when compared with its value in agriculture or aquaculture.

Ecological footprints quantify human–ecosystem relationships by estimating the land area required to supply the consumed ecosystem services in a sustainable manner. In particular, linking footprint area, an estimate of the scale of consumption–production relationships, with economic valuation, may provide a useful metric for estimating the spatial variation in the value of the ecosystem service being provided. This valuation can then be properly accounted for in water management and pricing strategies. These two approaches have been linked by calculating the price per footprint area using an empirical analysis of the revenue and expenditures from water utilities of cities and the spatial pattern of renewable water production [33]. The spatially heterogeneous ecological footprint method computes the area required to supply the water demand of a city based on the regional pattern of water run-off and its demand.

The valuation of renewable energy resources takes place indirectly through the replacement cost of non-renewables. This method is required for the construction of the Index of Sustainable Welfare (ISEW) and Genuine Progress Indicator (GPI). In the context of these indexes, it is required that non-renewable resources should be fully replaced by renewable resources in the future [31,32]. Another study by Richards, discusses not only the replacement cost but also an imposition of royalty rates on revenues from the mined (non-renewable) product, in contrast to royalty rates on profit that would be

invested back to society [35]. This constitutes another indirect form of renewables evaluation.

Another indirect renewables evaluation method is the abatement cost and damage cost approaches in the external costs produced by non-renewables. Since the application of renewables saves the abatement cost or the damages caused by the non-renewables, then the benefit of renewables is, among others, the abatement and damage cost of non-renewables. Therefore, the cost information in this case is used as a proxy for the benefit. The abatement cost approach uses the costs of controlling or mitigating damage from, for example, emissions as an implicit value for the damage avoided. The damage cost approach aims at empirically measuring the actual costs and benefits of externalities. It can be subdivided into two main categories: top-down, and bottom-up. Top-down approaches make use of highly aggregated data to estimate costs of particular pollutants, i.e., estimated national damages are divided by total pollutant depositions to produce a measure of physical damage per unit of pollutant. These physical damages are then attributed to power plants and converted to damage costs using available monetary estimates on the damages arising from the pollutants under study. In the bottom-up approach, damages from a single source are typically quantified through damage functions/impact pathways, and monetized using established economic valuation methods (e.g., contingent valuation, travel costs, etc.) [34].

Short-cut techniques make use of surrogate prices, which are market prices of goods related in some way to the environmental value, often as a direct substitute. Other short-cut techniques make use of market prices but emphasize the cost side. For example, the value of an environmental impact can be measured by estimating the cost of replacing or reproducing the environmental service or benefits lost. Related to these methods is the indirect opportunity cost method, which considers the labor time involved in collecting or harvesting natural resource products and values them with a local wage rate [36].

Discounted flow analysis, sensitivity and multicriteria analysis are used to evaluate projects based on renewable energy [37,41]. Multicriteria evaluation encompasses the attitudes of all stakeholders and various valuation criteria such as conventional energy saved, local energy availability, return of investment, contribution to regional economy, number of jobs created in the area, and potential controversies with other uses. The environmental impact criterion suggests that land use requirements, esthetic considerations, waste generation, water pre-requisites, and life cycle analysis of the technologies considered, should be taken into account.

Examples of studies discussed in this section are an economic assessment of electricity generation through wind energy that takes into consideration the interest recovery factor, the lifetime of the wind energy conversion system, the investment rate and operation and maintenance costs [38]. Another study uses a life cycle cost analysis in electricity generation systems [39], which allows the evaluation of all the costs associated with installing and operating any power system over its lifetime, thus allowing a reasonable comparison of different power sources. Moreover, life cycle cost analysis is used to compare costs of photovoltaics and grid electricity for a rural area and the result is, the cost is higher for the latter case [40]. Last, Tsagarakis and Papadogiannis [42] used total annual economic cost to prove that energy generated by the biogas of a wastewater treatment facility could be cheaper than the conventionally produced energy. Using the same criterion, it is proved that the involvement of more than one electricity generator units will avoid the loss of renewable energy produced by the biogass [43].

3. Conclusion

Benefits from renewable energy resources have attracted much the attention of academics and professionals especially after Kyoto Protocol. This topic is going to launch a bulk of forthcoming valuation studies, since capturing the economic value of the benefits from renewable energy sources and projects is currently at the center of policy making. Performing a cost–benefit analysis for a renewable energy project requires taking into account every possible economically relevant attribute of a project. However, not all attributes have acquired values so far. The process of assigning a value to them constitutes the valuation procedure. The cost–benefit analysis process as a whole is the evaluation. Sometimes these terms are wrongly used one in the place of the other. Most often studies mean to suggest evaluation but they wrongly use the term valuation instead. Therefore, a review of the valuation/evaluation studies in renewable energy resources, has led to the identification of three main categories of them.

Stated and revealed preference valuation methods constitute the first category. Valuation based on stated and revealed preferences produces the most inclusive values for renewable energy because they additionally take into account the non-use value of renewable energy. Studies using the stated preference methods contribute to the knowledge of consumers' preferences and actual surplus from the renewable energy usage. There is a considerable research shortage yet to be filled in the area of renewable energy compared to the vast work done in other areas of environmental and energy economics. For example, very little work has been done with hedonic pricing. Hence, it is difficult to implement a sort of meta-analysis having only a few studies in each category. However, this paper has summarized some general directions that will have to be verified though, in the near future, after more studies will have been implemented.

Second category is provided by studies using option theory and portfolio analysis that contribute to acknowledging and deriving a financial value of the flexibility renewable energy offers. This value should be embodied in the total value of renewable energy. The flexibility value is maybe more appreciated and understood by policy makers, but it is also a matter that should be explained to the general public, e.g., flexibility is an attribute that should be encompassed in a choice experiment on renewable energy and allow the public to form the social value of this attribute too.

Emergy analysis is an alternative to market valuation but by no means a substitute. This method is usually employed in ecological engineering and therefore is leveling and ignores all the aspects taken into account in stated preference methods. Because the latter are costly to undertake in all situations, some topics could be examined with emergy analysis, or use it as an alternative evaluation method for confirming purposes. The same applies for all the economics and accounting methods referred to in the last section of this paper, which are evaluation methods.

References

[1] Florida Power and Light Company. Available from: 〈http://www.fplenergy.com/〉 [accessed 12.12.2006].
[2] Awerbuch S, Sauter R. Exploiting the oil—GDP effect to support renewables deployment. Energy Policy 2006;34(17):2805–19.
[3] Union of Concerned Scientists. Available from: 〈http://www.ucsusa.org/clean_energy/renewable_energy_basics/public-benefits-of-renewable-energy-use.html〉 [accessed 12.12.2006].

[4] Renewable Choice Energy. Available from: 〈http://www.renewablechoice.com/index.php〉 [accessed 12.12.2006].
[5] SECSI, Solar Energy Society of Canada Inc. Available from: 〈http://www.newenergy.org/secsi/publication/pamphlets/renewable.html〉 [accessed 12.12.2006].
[6] Hanley N, Spash CL. Cost-benefit analysis and the environment. UK: Edward Elgar; 1993. pp. 278.
[7] Bateman IJ, Langford IH. Non-users' willingness to pay for a national park: an application and critique of the contingent valuation method. Reg Stud 1995;31(6):571–82.
[8] Carson RT. Contingent valuation: a user's guide. Environ Sci Technol 2000;34(8):1413–8.
[9] Hanley N. Cost-benefit analysis and environmental policymaking. Environ Plann 2001;19(1):103–18.
[10] Carson RT, Flores NE, Meade NF. Contingent valuation: controversies and evidence. Environ Resour Econ 2001;19(2):173–210.
[11] Nomura N, Akai M. Willingness to pay for green electricity in Japan as estimated through contingent valuation method. Appl Energy 2004;78(4):453–63.
[12] Begoña A, Hanley N. Using conjoint analysis to quantify public preferences over the environmental impacts of wind farms. An example from Spain. Energy Policy 2002;30(2):107–16.
[13] Hanley N, Nevin C. Appraising renewable energy developments in remote communities: the case of the North Assynt Estate Scotland. Energy Policy 1999;27(9):527–47.
[14] Wiser R. Using contingent valuation to explore willingness to pay for renewable energy: a comparison of collective and voluntary payment vehicles. Ecol Econ 2006;62(3–4):419–32.
[15] Ek K. Public and private attitudes towards "green" electricity: the case of Swedish wind power. Energy Policy 2005;33(13):1677–89.
[16] Borchers AM, Duke JM, Parsons GR. Does willingness to pay for green energy differ by source? Energy Policy 2007;35(6):3327–34.
[17] Roe B, Teisl MF, Levy A, Russell M. US consumers' willingness to pay for green electricity. Energy Policy 2001;29(11):917–25.
[18] Batley SL, Colbourne D, Fleming PD, Urwin P. Citizen versus consumer: challenges in the UK green power market. Energy Policy 2001;29(6):479–87.
[19] Wood LL, Kenyon AE, Desvousges WH, Morander LK. How much are customers willing to pay for improvements in health and environmental quality? Electr J 1995;8(4):70–7.
[20] Close J, Pang H, Lam KH, Li T. 10% from renewables? The potential contribution from an HK schools PV installation programme. Renewable Energy 2006;31:1665–72.
[21] Zarnikau J. Consumer demand for 'green power' and energy efficiency. Energy Policy 2003;31(15):1661–72.
[22] Siddiqui A, Marnay C, Wiser R. Real options valuation of US federal renewable energy research, development, demonstration, and deployment. Energy Policy 2007;35(1):265–79.
[23] Bolinger M, Wiser R, Golove W. Quantifying the value that wind power provides as a hedge against volatile natural gas prices. In: Proceedings of WINDPOWER 2002, June 2–5, 2002, Portland, Oregon. Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory, University of California, June 2002 Available from: 〈http://eetd.lbl.gov/EA/EMP/〉.
[24] Davis GA, Owens B. Optimizing the level of renewable electric R&D expenditures using real options analysis. Energy Policy 2003;31(15):1589–608.
[25] Yu W, Sheblé GB, Peças Lopes JA, Matos MA. Valuation of switchable tariff for wind energy. Electr Power Syst Res 2006;76(5):382–8.
[26] Venetsanos K, Angelopoulou P, Tsoutsos T. Renewable energy sources project appraisal under uncertainty: the case of wind energy exploitation within a changing energy market environment. Energy Policy 2002;30(4):293–307.
[27] Martin J. Emergy valuation of diversions of river water to marshes in the Mississippi River Delta. Ecol Eng 2002;18(3):265–86.
[28] Higgins J. Emergy analysis of the Oak Openings region. Ecol Eng 2003;21(1):75–109.
[29] Costanza R, Farber S, Maxwell J. Valuation and management of wetland ecosystems. Ecol Econ 1989;1(4):335–61.
[30] MacLeod M, Moran D, Spencer I. Counting the cost of water use in hydroelectric generation in Scotland. Energy Policy 2006;34(15):2048–59.
[31] Lawn P. An assessment of the valuation methods used to calculate the index of sustainable economic welfare (ISEW), genuine progress indicator (GPI), and sustainable net benefit index (SNBI). Environ Dev Sustainability 2005;7(2):185–208.

[32] Neumayer E. On the methodology of ISEW, GPI and related measures: some constructive suggestions and some doubt on the 'threshold' hypothesis. Ecol Econ 2000;34:347–61.
[33] Jenerette G, Marussich W, Joshua P, Newell J. Linking ecological footprints with ecosystem valuation in the provisioning of urban freshwater. Ecol Econ 2006;59(1):38–47.
[34] Sundqvist T. What causes the disparity of electricity externality estimates? Energy Policy 2004;32(15): 1753–66.
[35] Richards J. ''Precious'' metals: the case for treating metals as irreplaceable. J Cleaner Prod 2006;14(3–4): 324–33.
[36] Knowler D. 'Short Cut' techniques to incorporate environmental considerations into project appraisal: an exploration using case studies. J Environ Plann Manage 2005;48(5):747–70.
[37] Weisser D. Costing electricity supply scenarios: a case study of promoting renewable energy technologies on Rodriguez, Mauritius. Renewable Energy 2004;29(8):1319–47.
[38] Marafia A-H, Ashour H. Economics of off-shore/on-shore wind energy systems in Qatar. Renewable Energy 2003;28(12):1953–63.
[39] El-Kordy MN, Badr MA, Abed KA, Ibrahim Said MA. Economical evaluation of electricity generation considering externalities. Renewable Energy 2002;25(2):317–28.
[40] Bhuiyan MMH, Asgar MA, Mazumder RK, Hussain M. Economic evaluation of a stand-alone residential photovoltaic power system in Bangladesh. Renewable Energy 2000;21:403–10.
[41] Polatidis H, Haralambopoulos DA. Local renewable energy planning: a participatory multi-criteria approach. Energy Sources 2004;26(13):1253–64.
[42] Tsagarakis KP, Papadogiannis Ch. Technical and economic evaluation of the biogas utilization for energy production at Iraklio municipality, Greece. Energy Convers Manage 2006;47(7–8):844–57.
[43] Tsagarakis KP. Optimal number of energy generators for the biogas utilization in wastewater treatment facility. Energy Convers Manage 2007, in press.
[44] Ivanova G. Queensland consumers' willingness to pay for electricity from renewable energy sources. Available from: 〈http://www.anzsee.org/anzsee2005papers/Ivanova_%20WTP_for_renewable_energy.pdf〉 [accessed 30/12/2006].
[45] Bergmann A, Hanley N, Wright R. Valuing the attributes of renewable energy investments. Energy Policy 2006;34(9):1004–14.
[46] Felder F. Integrating financial theory and methods in electricity resource planning. Energy Policy 1996;24(2):149–54.
[47] Awerbuch S. Investing in photovoltaics: risk, accounting and the value of new technology. Energy Policy 2000;28(14):1023–35.
[48] Kumbaroğlu G , Madlener R, Demirel M. A real options evaluation model for the diffusion prospects of new renewable power generation technologies. Energy Econ 2007, in press.
[49] Shapiro A. Multinational financial management. 5th ed. Englewood Cliffs, NJ: Prentice-Hall; 1996. p. 844.
[50] Copeland TE, Weston JF. Financial theory and corporate policy. 3rd ed. Reading, MA: Addison-Wesley; 1992. p. 946.
[51] Pulselli RM, Pulselli FM, Rustici M. Emergy accounting of the Province of Siena: towards a thermodynamic geography for regional studies. J Environ Manage 2006, in press.
[52] Awerbuch S. The problem of valuing new energy technologies. Energy Policy 1996;24(2):127–8.